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## Cost Analysis of In-House Heat Substations in Next Generation Heat Networks

Sandra Šlihte<sup>a,\*</sup>, Maija Križmane<sup>a</sup>, Egīls Dzelzītis<sup>a</sup>

<sup>a</sup> Riga Technical University, Kalku iela 1, Riga LV-1658, Latvia

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### Abstract

Lowering the district heating supply temperature is crucial for improving the efficiency of the heat network. A developed concept of fourth generation low temperature district heating with supply temperature just above the required end user conditions allows for heat loss reduction, increases the plant room efficiency and enables the integration of alternative energy source for heat production. Due to the lowered temperature approach the cost of the in-house substation increases. This paper presents analysis of the cost increase of the in-house heat substation to enable the cost-benefit analysis of next generation district heating systems while considering new and refurbished systems. Heat transfer calculation software tool has been used to analyse the cost increased of the substation due to required high performance of the plate heat exchanger while considering that the rest of the components are the same model/size, including heat meter, control valve and pipework. It is concluded in this paper that by an accurate design of the in-house systems it is feasible to provide a cost effective solution of in-house heat substations operating in next generation heat networks.

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*Keywords:* district heating; low temperature; heat substation; heat exchanger

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### 1. Introduction

The heat network supply temperature is the parameter that significantly affects and limits the efficiency of the district heating system, therefore a concept of fourth generation heat network has been developed, where the primary supply temperature is lowered to below 55 °C. This increases the efficiency of heat networks by reducing the distribution heat loss and allows the implementation of renewable and low carbon emission energy source. The

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\* Corresponding author. Tel.: +44 7847 892579.

E-mail address: [sandra.slihte@gmail.com](mailto:sandra.slihte@gmail.com)

supply temperature reduction is limited to a temperature that will ensure that the end-user's space heating and domestic hot water comfort as well as sanitary requirements are met. A number of fourth generation heat network pilot projects have proven that the district heating supply temperature can be reduced to 55 °C and kept low all year around without sacrificing the end-user's comfort [1]. This requires the use of low temperature heat emitters and efficient heat substations for domestic hot water production.

To allow for the reduction in supply temperatures in fourth generation heat networks, the reduced flow and return temperature approach is required across the plate heat exchanger used in the in-house heat substation. The minimum domestic hot water supply temperature is typically required by the national standard, due to the threat of Legionella bacteria outbreak. The minimum hot water temperature is defined in Danish Standard 439 as 50 °C allowing the temperature to drop to 45 °C during peak periods. [2] German Technical regulations DVGW 551 makes no requirement if the overall hot water volume is below 3 liters [3]. British Standard BS 5885 requires 50 °C delivered to the hot water outlets or thermostatic mixing valves [4].

Previous studies of hot water production in low temperature heat networks are based on 'the rule of 3 liters' [5], however in this paper, the minimum hot water temperature is assumed to be 50 °C to reflect current requirements in heat substation design.

In-house heat substations are designed to provide hot water and heating typically for a single family home. In this study three scenarios have been considered for the peak domestic hot water draw off at 10, 12 and 14 liters per minute at 50 °C and the cold water temperature is assumed to be 10 °C.

### Nomenclature

|              |  |
|--------------|--|
| $\Delta p$   | total primary side pressure drop of the heat substation, kPa   |
| LMTD         | logarithmic mean temperature difference in heat substation, °C |
| $\Delta T_A$ | flow temperature approach of the heat substation, °K           |
| $\Delta T_B$ | return temperature approach of the heat substation, °K         |
| w            | weight increase ratio of the plate heat exchanger              |
| v            | volumetric size increase ratio of the plate heat exchanger     |
| $f_{HS}$     | cost increase ratio of the in-house heat substation            |

## 2. Methods

To establish the cost increase factor, the following steps have been outlined.

### 2.1. Reference and analysis condition selection

Current heat networks in Europe operate with supply temperatures of up to 110 °C in winter and 65 °C in summer depending on the local conditions. The report summarizing research findings of existing heat networks in United Kingdom established that existing networks can deliver required end user heating and domestic hot water demand with supply temperature of 70 °C [6] also meeting the maximum safe supply domestic hot water temperature that can be set as a minimum by national standards. The guidelines [8] would advise to have a low return temperature of 25°C when supplying hot water. Therefor the reference primary flow and return temperature conditions for the domestic hot water plate heat exchangers are selected to be 70/25°C. This condition is used to determine the size and weight increase of the plate heat exchanger.

The published literature on fourth generation heat networks define the primary temperature as 55 °C or lower and secondary temperature of 50 °C or lower. This study will analyse the heat substation design with the lowered flow and return approach temperatures between 1 and 5 °K. The resulting logarithmic mean temperature difference LMTD is used to demonstrate and compare the conditions reviewed:

$$LMTD = (\Delta T_A - \Delta T_B) / (\ln \Delta T_A - \ln \Delta T_B) \quad (1)$$

## 2.2. The plate heat exchanger selection for the instantaneous domestic hot water production with lowered supply temperature

The heat-transfer calculation software tool provided by the plate heat exchanger manufacturer is used to select the plate heat exchanger at the defined conditions [8]. The detailed requirements for the selection of the plate heat exchangers are described in the publication [7], and are as follows:

- Turbulent fluid flow in the plate heat exchanger – to ensure the heat transfer and self-cleaning effect for the plate heat exchanger it is selected based on the Reynolds number for the fluid in the brazed heat exchanger under the operating conditions greater than 150 [10].
- Total pressure drop – the total pressure drop across the components on the primary side of the heat substation including heat meter should not exceed 50kPa under the peak demand. This requirement is to optimise the pumping costs. The following components are considered: stainless steel DN20 pipework, heat meter with  $k_{vs}$  value of 3 [11], control valve minimum differential pressure considered constant at 25kPa and the plate heat exchanger [9]. The total pressure drop  $\Delta p$  in kPa of the heat substation components is calculated as follows:

$$\Delta p = \Delta p_p + \Delta p_{hm} + \Delta p_{cv} + \Delta p_{ph} \quad (2)$$

## 2.3. Establishing the weight and volumetric size factor increase of the selected plate heat exchanger

The weight and volumetric size increase ratio is established to enable the analysis of the heat substation's cost increase. These two values show the ratio of the weight or volumetric size of the plate heat exchanger selected for the typical conditions and the low heat network supply temperature.

The LMTD for the reference conditions is 17.83 °K. The following values are for the selected plate heat exchanger operating at reference conditions and are used for further calculations.

Table 2. Reference conditions used for calculations

| Domestic hot water flow rate, l/min | Volumetric plate heat exchanger size, mm <sup>3</sup> | Plate heat exchanger weight, kg |
|-------------------------------------|---|---------------------------------|
| 10                                  | 932,400   | 1.64                            |
| 12                                  | 1,030,302   | 1.75                            |
| 14                                  | 1,226,106   | 1.99                            |

The chart below shows the calculated volumetric size increase ratio depending on LMTD for the three selected domestic hot water loads.

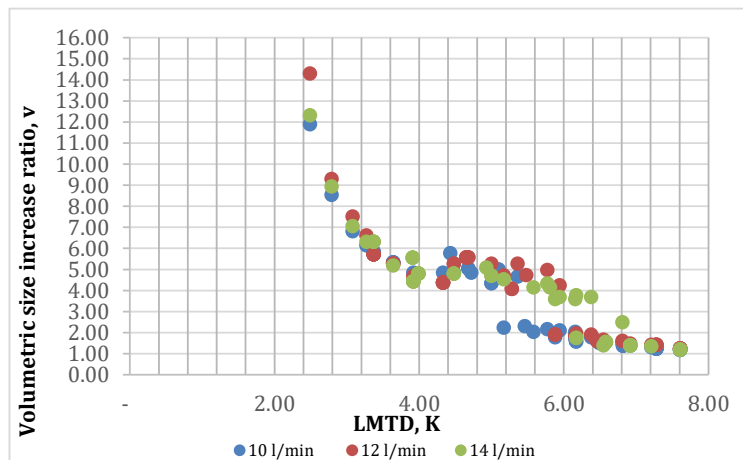


Fig. 1 Volumetric size increase ratio dependency on LMTD, DHW draw off at 50 °C [7]

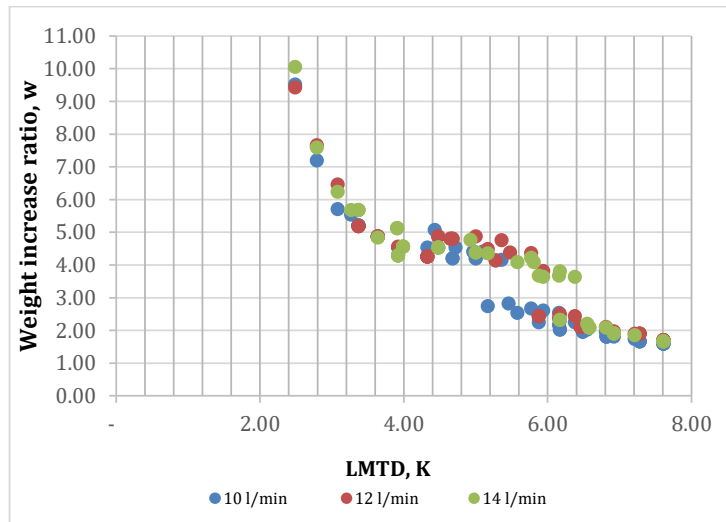


Fig. 2 Weight increase ratio dependency on LMTD, DHW draw off at 50 °C [7]

Figure 1 and Figure 2 above show that the volumetric size and weight increases as the LMTD is reduced. The above results are used in the further calculation for the total cost increase calculation.

The selected plate heat exchanger for analysis conditions height dimension is compared to the one of the reference conditions, to establish if the pipework length will increase. The selection showed that the factor of 1.275 should be applied to some conditions under the analysis.

#### 2.4. Determining the cost increase of the in-house heat substation if the temperature approach is reduced

In this study it is considered that the cost increase of the in-house heat substation consists of the following elements:

- Plate heat exchanger weight increase is proportional to it's cost
- Plate heat exchanger volumetric size increase is proportional to the plate heat exchanger's insulation cost
- The plate heat exchanger height increase will increase the required pipework length
- Plate heat exchanger volumetric size increase is proportional to the cost of the in-house heat substation casing
- The other component's cost like heat meter, control valve has been considered constant.

Table 2. Component cost proportion

| Component   | Proportion |
|---|------------|
| Plate heat exchanger  | 0.14       |
| Plate heat exchanger insulation   | 0.02       |
| Pipework  | 0.10       |
| Case  | 0.13       |
| Other fittings (control valve, heat meter, sensors, fittings and other) | 0.61       |

The above values have been established based on the market data and can vary depending on the manufacturer and type and cost of components used. To demonstrate the cost increase ratio the above values are used t

$$f_{HS} = (0.14 \times w) + (0.02 \times v) + (0.13 \times v) + (0.1 \times 1.275) + 0.61 \quad (2)$$

The equation above takes into account the cost increase of the components due larger plate heat exchanger model selection. If the substation price is increased due to the weight increase of the component, the weight increase factor  $w$  is used, if it is due to the physical size of the component, the volumetric size factor  $v$  is used in the above equation.

### 3. Results

The results are demonstrated as a ratio of the cost when plate heat exchanger and other components used in heat substations designed to operate under reference conditions shown in Table 2 and are based on the primary flow and return temperatures 70 °C and 25 °C accordingly. LMTD for reference case scenario is 17.83 °K. The below shows the factor increase of the cost of the in-house heat substation dependency on LMTD.

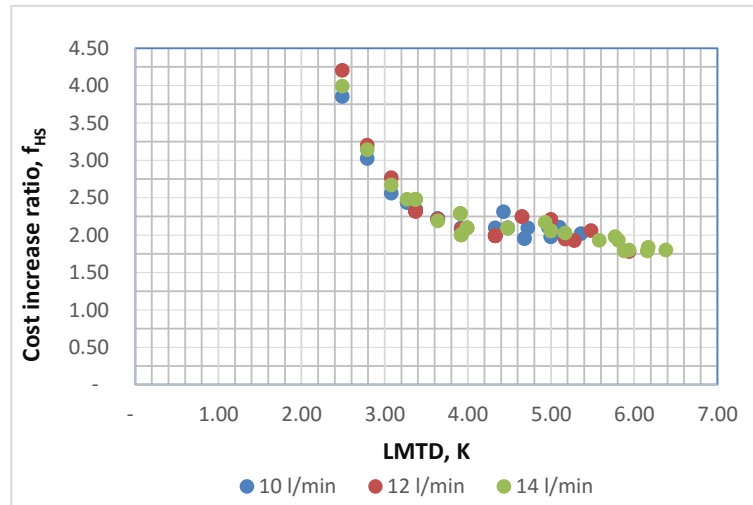


Fig. 3 Cost increase ratio of the in-house heat substation dependency on LMTD, DHW draw off at 50 °C

The results illustrated in Figure 3 shows that by utilizing low temperature district heating networks, the investment cost of the in-house heat substation would increase between 1.78 up to 4.25 times. It also shows that the cost increases rapidly, if the LMTD is reduced to 3.4 °K and lower.

The results could be used when specifying the temperature approach for the project depending on the minimum domestic hot water temperature and required peak domestic hot water load. While lowering the temperature approach is significant for improving the efficiency of the system, the feasible temperature should be defined. The performance of the plate heat exchanger under partial loads and low loads should also be analysed before specifying a low temperature approach to ensure it is not oversized.

### 4. Conclusions

The results demonstrate that with the current plate heat exchanger technology available, it is possible to provide instantaneous domestic hot water production for single-family homes in fourth generation district heating networks, however higher investment cost of the heat substations should be considered due to increase of the size and weight of the plate heat exchanger required. The optimum and feasible temperature approach can be selected from the results for the specific project. The results enable further cost-benefit analysis to be carried out for next generation heat networks at the feasibility stage.

Further tests should be carried out of the heat substation performance under partial and small loads to ensure that the plate heat exchanger is not oversized and the turbulent flow in it is ensured. This is significant as the substation is used under partial load for the majority of the time and rarely under the peak load.

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